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ARPA E Cement Annual Meeting 2021
The Roadmap to Carbon Neutrality

Rick Bohan, PE, FACI, VP Sustainability

October 14, 2021 | Virtual

COOPERATION / COLLABORATION / COORDINATION

gcca

CEMBUREAU
The European Cement Association

vdz.

Cement Association of Canada

CSHub
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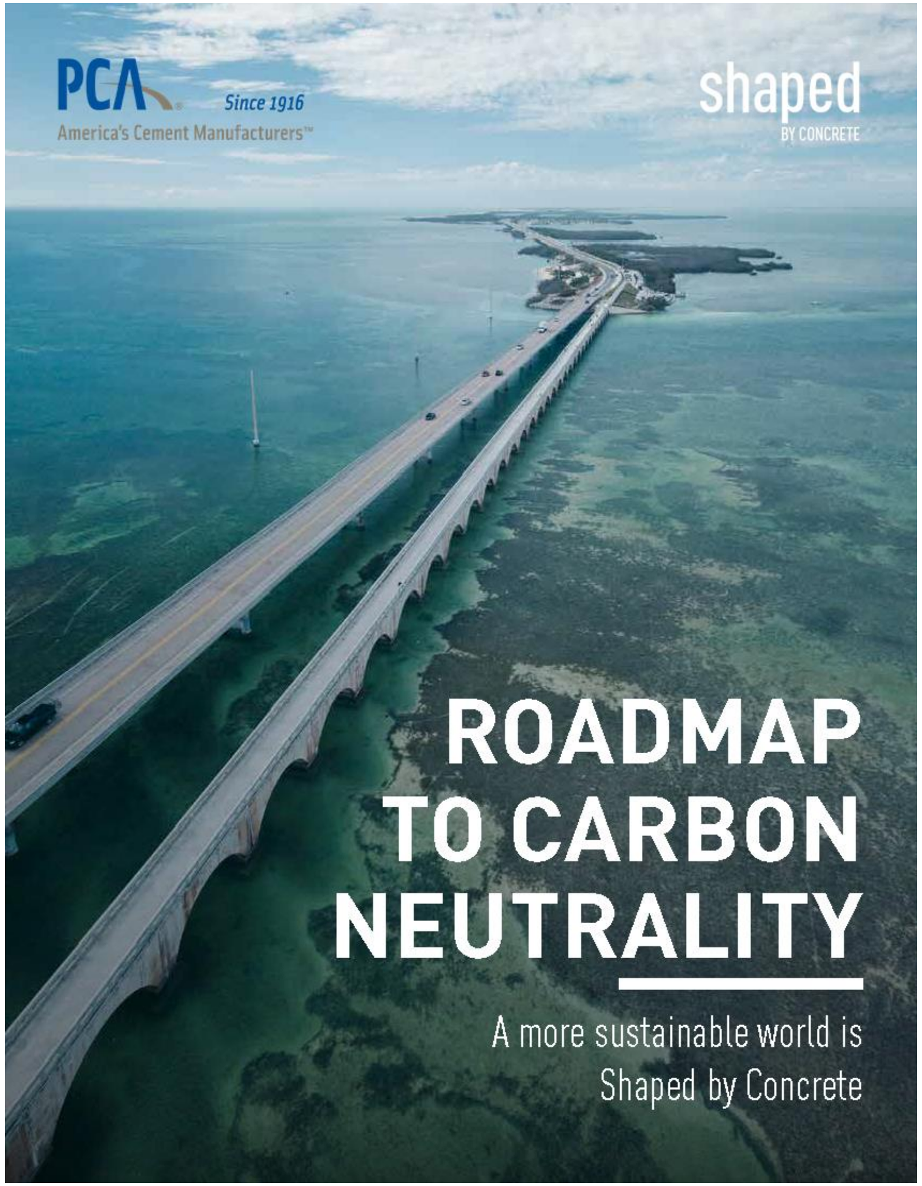
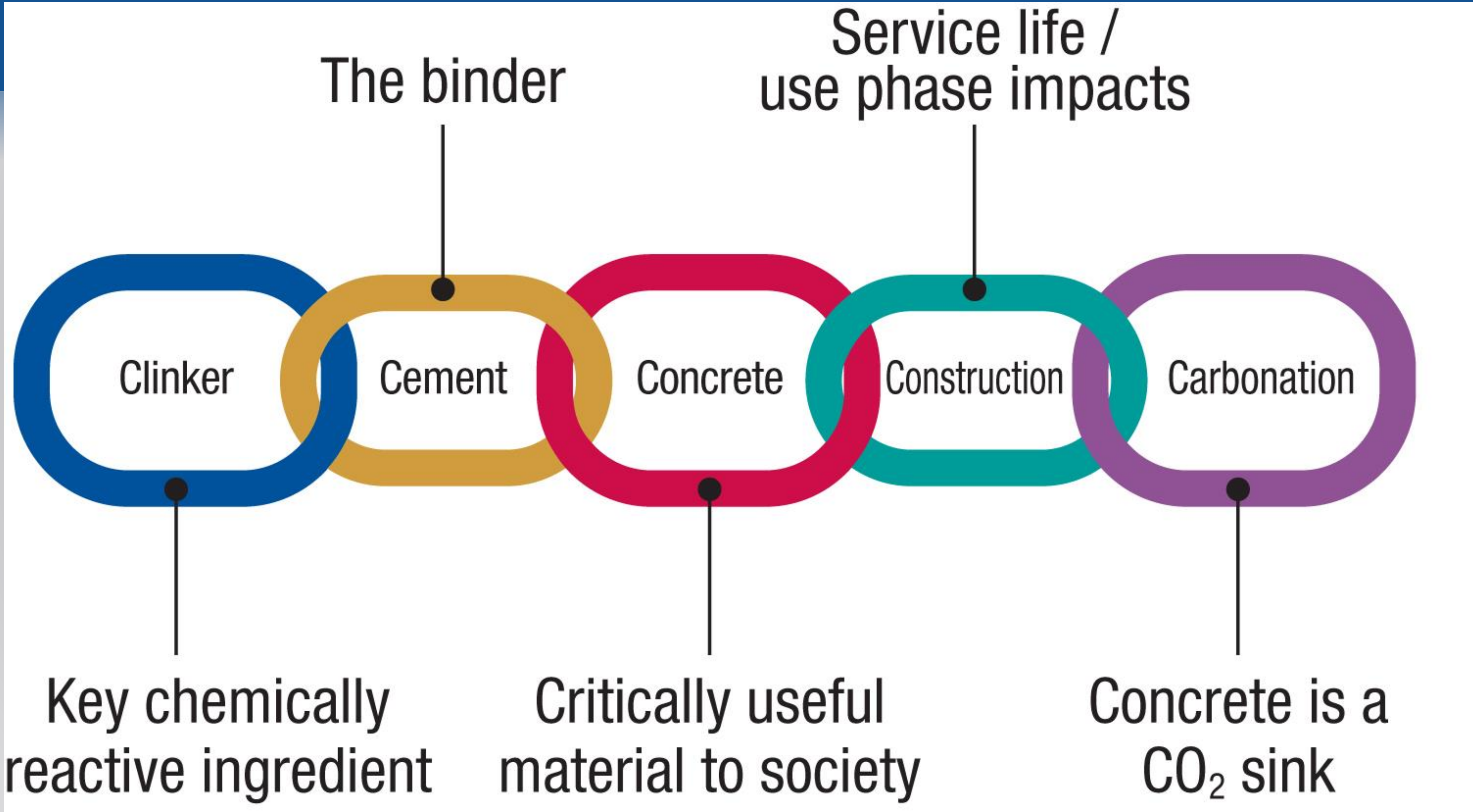
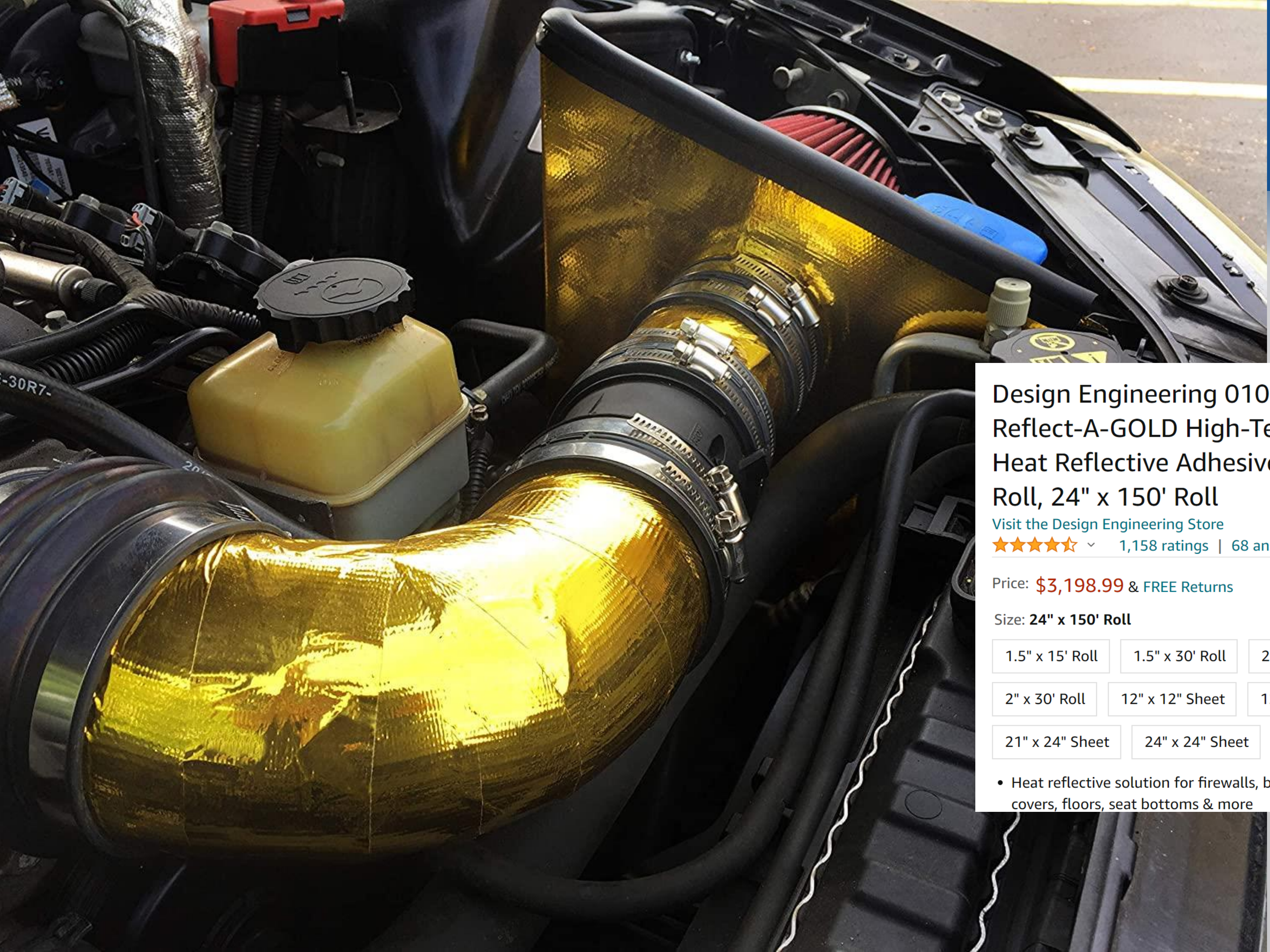
NATIONAL READY MIXED CONCRETE ASSOCIATION



AVAILABLE ONLINE AT WWW.CEMENT.ORG


The binder
Service life /
use phase impacts
Clinker
Cement
Concrete
Construction
Carbonation
Key chemically
reactive ingredient
Critically useful
material to society
Concrete is a
CO_2 sink



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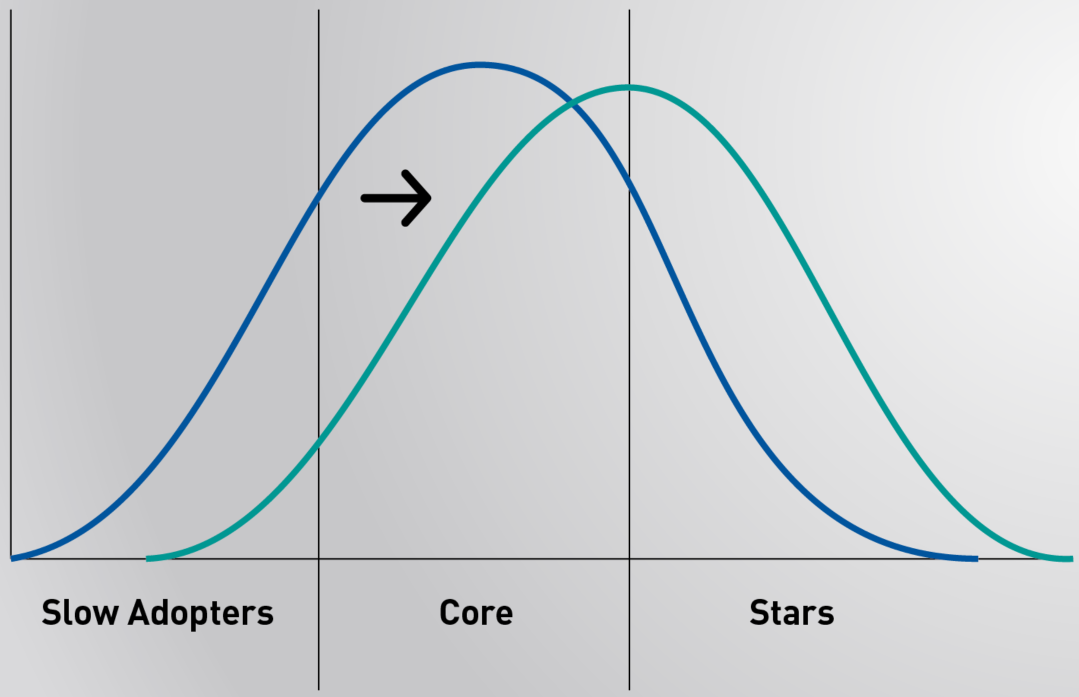
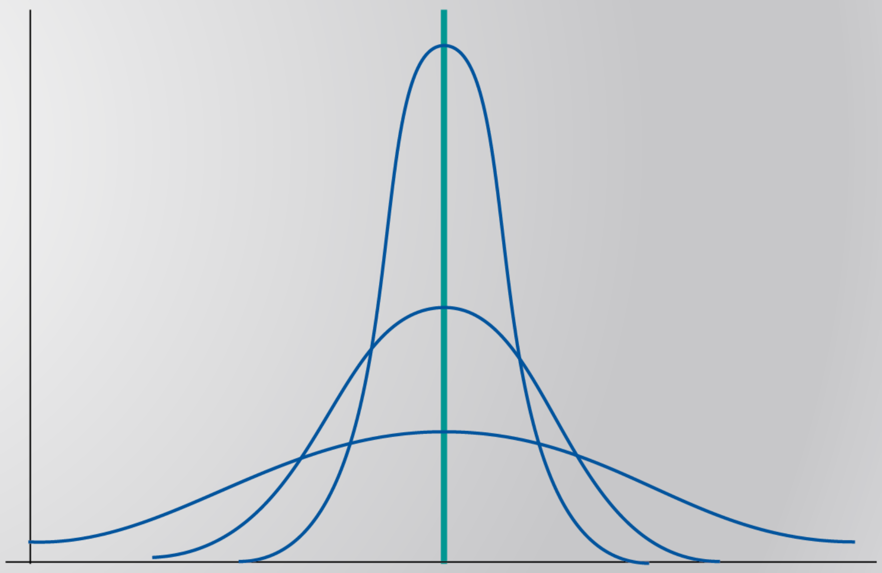
OPTIMIZATION: SHIFTING THE CURVE AND SHAPING THE CURVE

Shifting the Curve



Shaping the Curve



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SOCIETY NEEDS CONCRETE…
AND
CONCRETE NEEDS SOCIETY!!

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OPTIMIZING CLINKER

- Increased use of decarbonated/pre-calcined raw materials like slag
- Efficiency gains
- Fuel switching/fuel substitution/renewables
- Transformative fuels and technologies: H_2, plasma heating, oxyfuel/oxy-calcination, electric calcination…
- CCUS: solvents, sorbents, membranes, algae…

CCUS

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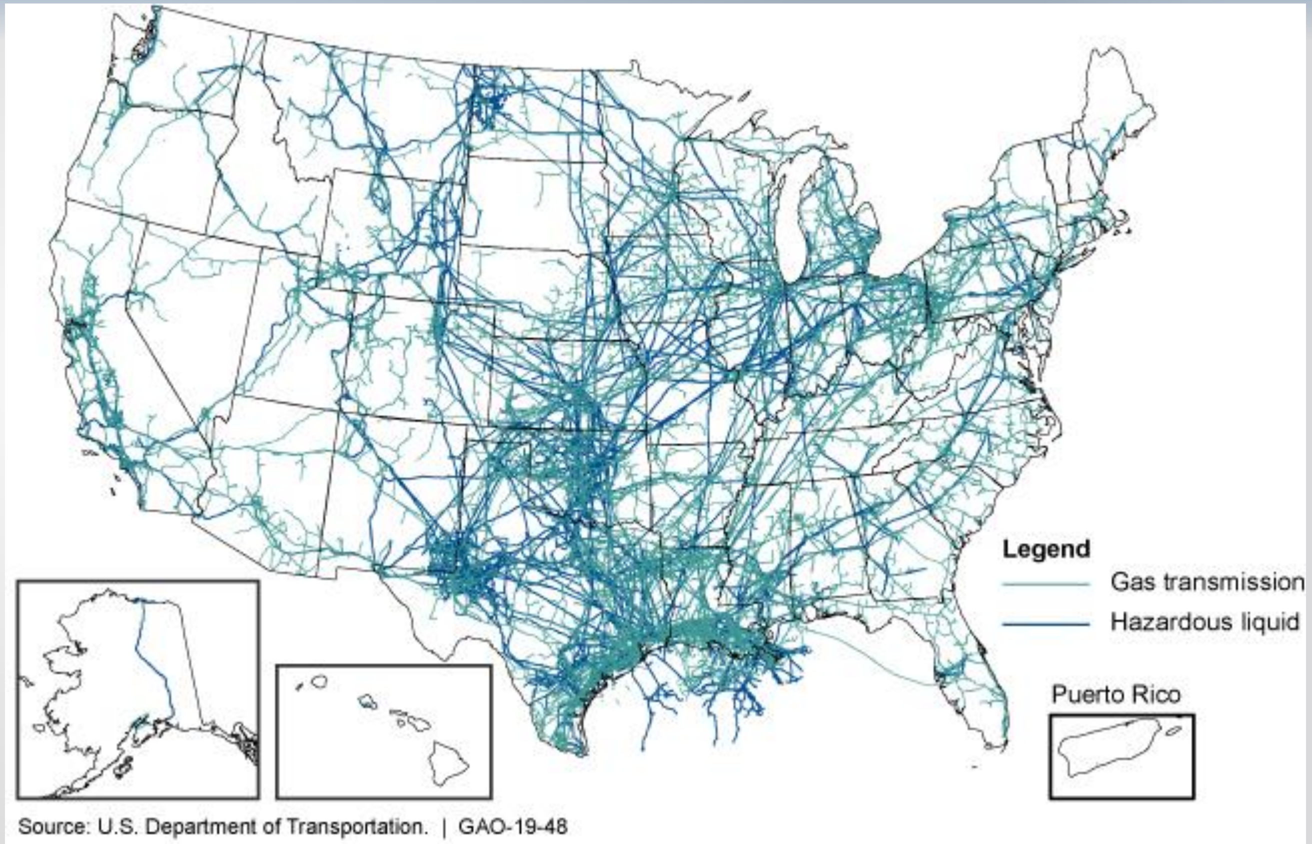
Infrastructure Needs



OPTIMIZING CEMENT

U.S. CEMENT INDUSTRY CONTRIBUTION TO GLOBAL GHG = 0.17% CO_{2EQ}

U.S. CEMENT INDUSTRY CONTRIBUTION TO U.S. GHG = 1.25% CO_{2EQ}

- Appropriate clinker to cement ratio
- Increased use of non-gypsum additions
- Flexibility in standards and specifications: P2P
- Universal acceptance/adoption of PLCs
- New cements
- Zero emissions manufacturing & transportation

OPTIMIZING CONCRETE

- Improvements in mix design
- Increasing supplementary cementitious materials like slag, fly ash, silica fume, and other additives
- Reduced concrete plant energy consumption/reduced concrete delivery energy consumption
- Breakthrough technologies

IMPROVEMENTS IN MIX DESIGNS

- Shift from prescriptive to performance-based specifications
- Shift from prescriptive-based pre-qualification testing to performance-based standards
- Incentivizing innovation instead of institutionalizing inertia
- Accelerating the adoption of proven solutions
- Performance-engineered mixtures (PEM)
  - Leverage developments in concrete testing technologies to better predict long-term performance
- AI to design the right mix using the right materials for the right application to achieve the right performance

OPTIMIZING CONSTRUCTION

- Optimization in each phase of construction:
  - Design: 3D modeling, virtual reality design, etc.
  - Construction: zero waste, sequencing, scheduling, zero emission delivery and materials handling
  - Use: Focus on appropriate use of EPDs and LCCAs
  - End-of-life: Recognizing concrete as a carbon sink

7 INNOVATIONS THAT WILL CHANGE CONSTRUCTION AS WE KNOW IT

GRACE ELLIS SEPTEMBER 24, 2020 HTTPS://CONSTRUCTIONBLOG.AUTODESK.COM/CONSTRUCTION-INNOVATIONS/

1. AI for Construction Workflows
2. Resource and Workforce Management Software
3. The Next Wave of 3D Printing
4. AR + VR = Immersive Reality
5. Predictive Analytics and Machine Learning
6. Digital Twins
7. Truly Connected Construction

key findings

Compared to legacy stock buildings, GSA's high-performance buildings show:

- *23%* ↓ *energy use*
- *28%* ↓ *water use*
- *23%* ↓ *building operating expenses*
- *9%* ↓ *waste landfilled*
- *2%* ↑ *overall tenant satisfaction*

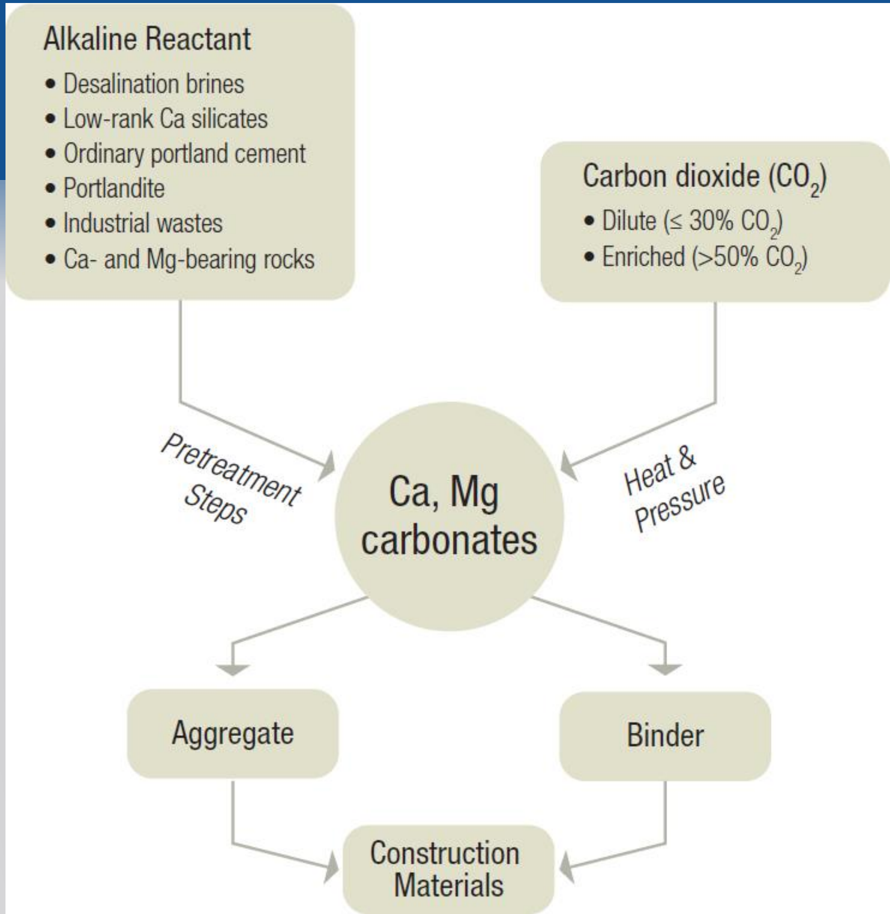
The Guiding Principles

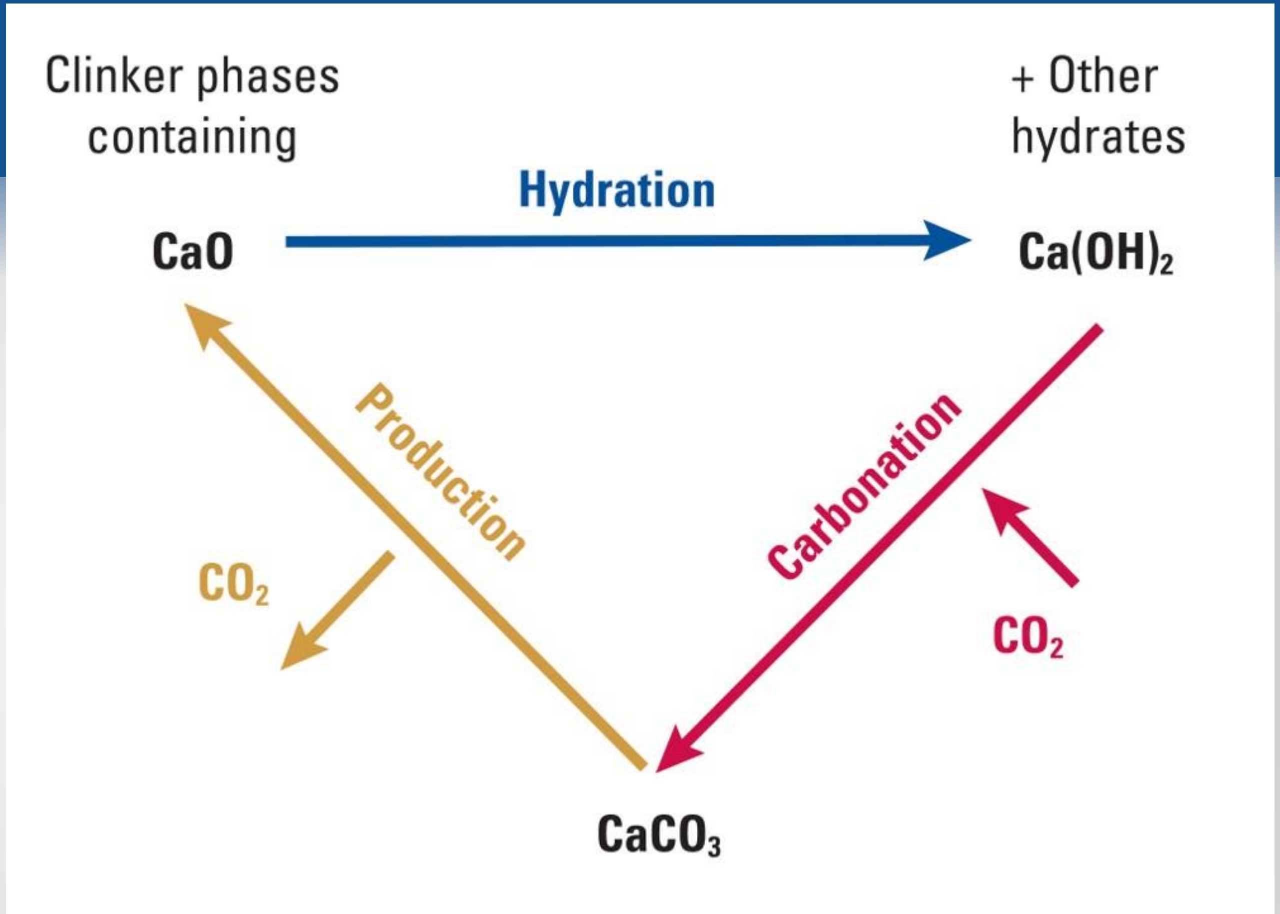
1. Employ integrated design principles
2. Optimize energy performance
3. Protect and conserve water
4. Enhance indoor environmental quality
5. Reduce environmental impact of materials
6. Assess and consider climate change risks

key findings

Compared to legacy stock buildings, GSA's high-performance buildings show:		***Compared to industry benchmarks, GSA's high-performance buildings show:***
23% ↓	*energy use*	↓ *43%*
28% ↓	*water use*	↓ *35%*
23% ↓	*building operating expenses*	↓ *10%*
9% ↓	*waste landfilled*	*not tracked*
2% ↑	*overall tenant satisfaction*	↑ *1%*

The Impact of High-Performance Buildings, U.S. General Services Administration, June 2018





~~Carbonation~~

Concrete as a Carbon Sink

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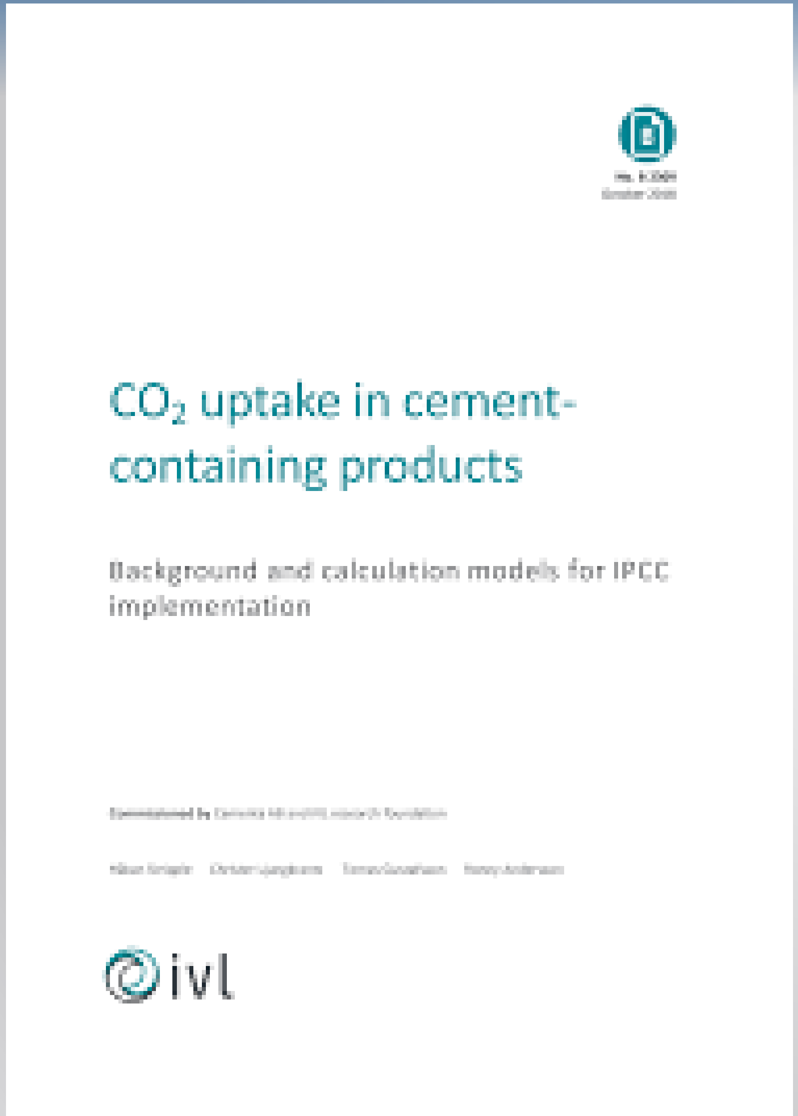
CONCRETE AS A CARBON SINK: THE SCIENCE



CO_2 uptake in cement-containing products

Background and calculation models for IPCC implementation

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ELSEVIER

Carbonation as a method to improve climate performance for cement based material

R. Andersson[a,*], H. Stripple[b], T. Gustafsson[b], C. Ljungkrantz[c]

[a] Until June 1th 2018, Lund University, Structural Engineering, Box 118, SE-221 00 Lund, Sweden
[b] IVL Swedish Environmental Research Institute, P.O. Box 53021, SE-400 14 Gothenburg, Sweden
[c] Cementa Ltd, Marieviksgatan 25, SE-117 43 Stockholm, Sweden

ABSTRACT

Concrete is today considered to be a crucial material in the ongoing complex transformation of our society in a sustainable direction. One prioritized requirement in this transformation is to reduce the emissions of CO_2 that are associated with concrete production and use. One well-known factor which, so far, has not been considered is (re)carbonation of built concrete products over their life cycle. This paper presents research to quantify such uptake in reports to the United Nations Framework Convention on Climate Change (UNFCCC). It also presents the current status of considering carbonation in the EU Emissions Trading System (EU ETS) and in International Environmental Product Declarations (EPD). The paper also presents some possibilities for further research on how to improve climate performance by considering carbonation.

1. Introduction

The paper deals with cement-based materials (concrete and mortar). The word *concrete* is however frequently used as a generic term and also used in this paper for both concrete and mortar. The term *cement* is used solely for "common" cements with Portland clinker as one component. Special cements are not treated, with the exception of a short mentioning in Chapter 4.1.

Concrete is the most used construction material in the world. Its use dates back to before and during the Roman Empire, but its modern use started around 200 years back with the introduction of industrial production of Portland cement. Raw materials for cement are globally widely available and today, the properties of concrete are well proven both in diverse climates and over a long timeframe. These properties are very suitable for sustainable construction.

However, one important aspect to consider is that cement production is a source of CO_2 emissions, mainly due to its high temperature process. A global average estimate of the emissions per tonnes clinker can be as 36% from use of fuels and 64% from calcination of limestone (a primary raw material) at high temperatures [1].

Several research and development activities related to cement are under way including fossil-free energy, complete electrification of the process, Carbon Capture Use or Storage (CCU/CCS), development of existing binders and additions, as well as introduction of new binders, [2,3]. It is also a development work that needs involvement of other construction actors, depending on the influence from design, manufacture, construction etc. as well as involving society's efforts to create a sustainable society. Reference [2] argues that with engagement from different actors and stakeholders, significant reductions in CO_2 emissions can be achieved.

Carbonation is a chemical reaction by which CO_2 penetrates the concrete and reacts with the hydration products, forming mainly calcium carbonate. Knowledge of carbonation of existing concrete structures is well-established. Both CSH gel (short for Calcium-Silicate-Hydrate) and $Ca(OH)_2$ form a part of the cured concrete. CO_2 in the atmosphere, in contact with concrete, will primarily react with $Ca(OH)_2$ in the concrete according to the principle reaction (1). below, but will also react with the CSH gel. These reactions, which describe the uptake of CO_2 in concrete, are called carbonation, see 1. below.

$$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O \quad (1)$$

The carbonation reaction takes place in several steps [4,23]. The actual uptake reaction between the calcium and carbonate ions takes place in the water phase of the pore solution in the concrete. Water and moisture are thus an important part of carbonation.

The table below, taken from FprCEN/TR 17310.2018 [18] (the figures are originally presented in [6]) provides the amount of CaO available for carbonation for the different reaction products for Portland cement (Table 1).

The table shows that also other reaction products, such as monosulphate and ettringite carbonate, but the quantity in common cements

* Corresponding author at: Cementa Ltd, Dockplatsen 1, SE-211 19 Malmö, Sweden.
E-mail addresses: ronny.andersson@kstr.lth.se, ronny.andersson@cementa.se (R. Andersson), hakan.stripple@ivl.se (H. Stripple), tomas.gustafsson@ivl.se (T. Gustafsson), christer.ljungkrantz@cementa.se (C. Ljungkrantz).

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THE BIG TEN

- Research, Development & Innovation
- Regulations, Permitting & Guidance
- Financial Incentives & Support
- Preformance-Based Material Standards
- Market-Based Carbon Pricing
- Market Acceptance
- Community Acceptance
- Cradle to Cradle Life Cycle-Based Procurement
- Low-Carbon Infrastructure
- Level Playing Field

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